

Before the  
Federal Communications Commission  
Washington, DC 20554

In the Matter of )  
Revision of Part 15 of the Commission's Rules ) ET Docket 98-153  
Regarding Ultra-Wideband Transmission )  
Systems )

COMMENTS OF LUCENT TECHNOLOGIES INC.

Lucent Technologies Inc. (Lucent) respectfully submits the following comments in response to the Commission's *Notice of Proposed Rulemaking* (Notice),<sup>1</sup> regarding ultra-wideband (UWB) technologies. As a global manufacturer of telecommunications network equipment, Lucent invests significant resources towards the research and development of innovative communications technologies, including UWB. In fact, Lucent, through its participation in the Wireless Information Networks Forum (WINForum), provided information relating to UWB research in response to the Commission's Notice of Inquiry in this proceeding.

Lucent agrees with the Commission's conclusion that UWB technologies may offer significant benefits to public safety entities and may provide alternative means for short-range broadband communications, similar to personal area networks being developed by IEEE 802.15. Accordingly, Lucent supports the Commission's investigation into the establishment of new rules for UWB devices. In particular, Lucent applauds the Commission's interest in understanding and minimizing the risks of interference presented by UWB devices before adopting any final UWB rules.

Lucent supports the Commission's evaluation of UWB devices and believes the approach taken by the Commission in setting both average and peak RF emission limits for general purpose UWB devices is essentially correct. Lucent agrees that the proposed levels are generally appropriate and provides some minor clarifications to the Commission's proposals on measurement methods and procedures. In addition, Lucent proposes a method to measure compliance with the proposed applicable limits. Finally, Lucent provides direct responses to particular questions raised in the Notice.

***Proposed Average and Peak Power Limits are Sufficient, Provided the Commission Clarifies Methodology of Average Power Measurement***

As noted by the Commission, UWB has the potential to provide many useful services. Lucent envisions short-range communications as being one of the primary

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<sup>1</sup> In the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, ET Docket 98-153, FCC 00-163 (rel. May 11, 2000).

applications of UWB technology and has therefore evaluated its characteristics and interference potential to PAN and LAN communications. While Lucent did not analyze UWB interaction with all of the other devices complying with current Commission rules, the findings are believed typical of other high bandwidth systems that may be affected by UWB interference and are representative of the impact faced by many other devices already authorized by the Commission. Our analysis yielded significantly different results for two modes of UWB operation, both allowed under the Notice's proposed rules change. Lucent feels these differences are an undesired result of an anomaly in the measurement technique currently specified when it is applied to UWB signals. The study assumed that UWB devices would comply with a proposed average limit of  $-41.2 \text{ dBm/MHz}^2$  and a peak power limit of  $-21.2 \text{ dBm/50 MHz}$ ,<sup>3</sup> and calculated the required distances to ensure reasonably interference-free operation. The required spacing between the UWB interferer and the 802.11 system is derived from the power limits for UWB and the receiver noise of the 802.11 victim system. When UWB devices are closer to an 802.11 receiver, the range over which the 802.11 system can operate shrinks proportionally.

UWB operating condition	Bandwidth = 700 kHz 802.11 FH 2.4 GHz	Bandwidth = 11 MHz 802.11 CCK 2.4 GHz	Bandwidth = 17 MHz 802.11 OFDM 5 GHz
Burst operation,* discrete spectrum**	26.8 m	19.3 m	11.4 m
Burst operation,* continuous spectrum**	< 26.8 m	19.3 m	11.4 m
Non burst operation, discrete spectrum	6.9 m	8.4 m	4.1 m
Non burst operation, continuous spectrum	12 m	14.1 m	8.9 m

\*Burst operation means the UWB device operates at a high repetition rate for short intervals that are not interpreted as high average power by the current Part 15 definition.

\*\*Imaging devices normally produce discrete line spectra. Communications devices normally produce continuous spectra.

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<sup>2</sup> See Notice paragraph 50

<sup>3</sup> See Notice paragraph 43

While Lucent believes the proposed average and peak power limits will result in acceptable interference distances for non-burst UWB operations,<sup>4</sup> as shown in the table above, interference distances for burst operations with other occupants of the spectrum will result in a significant increase in interference potential. The disparity in distances results from the nature of UWB burst operations and an anomaly in the current Part 15 average specification. The current Part 15 average specification measurement is a voltage (field strength) average taken over 100 ms. This is typically measured as the output of a spectrum analyzer with a 10 Hz video bandwidth filter and a 1 MHz resolution bandwidth filter. The average can exceed the specified limits if the equipment operates in bursts shorter than 10 ms (as specified) or about 3 ms (as measured) and operates at a reduced duty cycle. Thus, as a result of the existing average specification measurement criteria, UWB devices utilizing burst operations could comply with the rules and yet exceed the average power limits.

In paragraph 50 of the Notice, the Commission sought comment on the averaging specification and suggested the use of a 10 kHz video bandwidth filter for the average measurement. Although use of the 10 kHz filter would alleviate the average measurement problem, Lucent proposes an alternative solution that would encompass the Commission's 10 kHz suggestion, solve the measurement problem in its entirety, and reduce interference distances for burst operations to acceptable levels, without burdening UWB operations. Lucent's solution is to adopt the following proposed rule:

Average power in a 1 MHz bandwidth while a UWB device is operating shall result in a field strength less than or equal to the limits specified in Section 15.209. If the maximum time the device operates at the highest repetition rate is less than the integration time for determining the average power, then appropriate corrections shall be made to assure that the average power during the maximum repetition rate meets the above specified condition.

In addition, Lucent proposes adding a new paragraph to Section 15.35 of the Commission's Rules:

For UWB devices, the average power shall be measured over an interval that is no larger than the minimum interval the device operates at its maximum repetition rate. If this minimum interval exceeds 100  $\mu$ s, then the average envelope power may be measured using a video filter with a bandwidth of at least 10 kHz.

These proposed rule changes would align the interference distances for burst and non-burst operations without placing undue restrictions on UWB technologies or unreasonable testing burdens on UWB manufacturers.

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<sup>4</sup> Lucent views the proposed limits as acceptable maximum requirements. Lucent believes increased limits would result in unacceptably long interference distances for all devices.

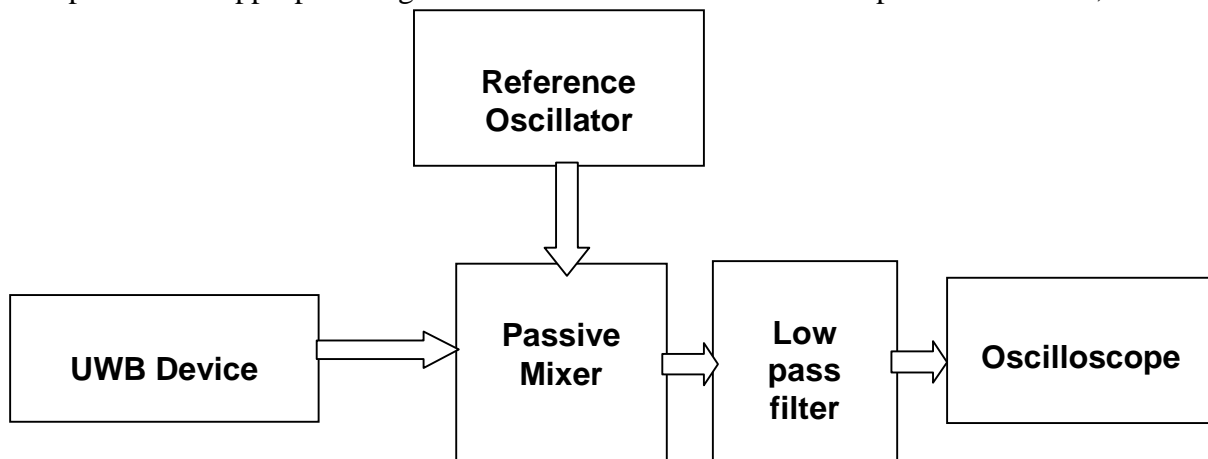
### ***Filter for Peak Power Measurement Must Be Precisely Specified***

Lucent agrees that a peak power limit is needed to minimize impact to existing services and systems. The Commission proposed a limit of  $-21.2 \text{ dBm}$ <sup>5</sup> measured through a filter with a 10 dB bandwidth of 50 MHz.<sup>6</sup> As pointed out in Annex 2, the properties of a commonly used filter of 50 MHz at  $-10 \text{ dB}$  corresponds to filter of 35 MHz at  $-3 \text{ dB}$ . A  $-3 \text{ dB}$  bandwidth is the appropriate measure for bandwidth in interference and noise analysis.

For the proposed measurements for the limits mentioned in paragraph 43 of the Notice, the filter characteristic must be specified more precisely than just by its  $-10 \text{ dB}$  points. In order to adequately define the operating limits and to ensure accuracy and consistency of measurements, a precise specification of the measurement filter is required. Because different orders of filter have different “shape factors” and “roll off,” Lucent suggests that a 4<sup>th</sup> order Butterworth characteristic within limits of a few dB be used to conduct these measurements.

### ***Methods of Peak Power Measurement Must be Specific and Easy to Replicate***

The Commission states in paragraph 53 of the Notice that spectrum analyzers may not provide the appropriate high resolution bandwidth. In order to produce accurate,



consistent results, measurement methods need to be specified in sufficient detail so as to eliminate misinterpretation of procedures or wide variations in results. To that end, Lucent proposes the following measurement set-up and procedure to verify compliance with the  $-21.2 \text{ dBm}$  limit.

The RF signal output of the device under test is connected to the RF input of a passive mixer.<sup>7</sup> The second input to this passive mixer is an RF oscillator signal from a RF

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<sup>5</sup> The Notice proposes a peak limit 20 dB above the average limit. The average power in a 1 MHz resolution bandwidth filter is limited to 500 microvolts/meter at 3 meters by 15.209 (a). This is an equivalent isotropic radiated power level of  $-41.2 \text{ dBm}$  for the average and  $-21.2 \text{ dBm}$  for the peak.

<sup>6</sup> See Notice at paragraph 43.

<sup>7</sup> For instance Mini-Circuits parts in the series ZEM- and ZMX

generator. The (IF) output of the passive mixer can be connected to a commercially available low pass filter<sup>8</sup> or a dedicatedly designed low pass filter based on modeling as described in literature or derived from computer programs. By changing the oscillator frequency over the range to be observed the operator can analyze the power level at any given frequency of interest.

The device under test is temporarily replaced by a calibrated reference RF power source fixed at the allowed limit of  $-21.2$  dBm. The observed signal on the oscilloscope is marked and serves as the reference for subsequent measurements.

The reference power source is disconnected and the device under test is connected to the mixer and activated. The observed signal on the oscilloscope should never exceed the reference level found when the reference  $-21.2$  dBm RF power source was connected.

Lucent believes this proposed method of measurement would be easily calibrated and readily repeatable. In fact, with manageable effort, it can be largely automated, including repeated calibration. This would be particularly important since many UWB components are frequency dependent.

### ***Answers to Questions Raised in the Notice***

#### ***§21 Definition of UWB and Requirements***

A loose definition of UWB, “devices employing emissions with a fractional bandwidth that exceeds .25,” appears adequate even though it does not encompass all possible uses for UWB devices.

#### ***§25 and 26 GPR definition and restrictions***

In broad terms, the proposed definition and restrictions appear to be appropriate.

#### ***§27 Restrictions on UWB above 2 GHz***

Based on our analysis of the interference potential of UWB devices, Lucent considers it absolutely necessary to establish both average and peak emission limits for UWB operations.

#### ***§34 Emission limits***

- 1) While the limit for unintentional radiators in Section 15.109 ( $150\mu\text{V/m}$  at 10 m distance) is useful for the assessment of interference by conventional devices, Lucent notes that it is not useful for UWB devices that have very different emissions.
- 2) The cumulative impact of multiple UWB devices can exceed the simple additive effect one would expect, because overlapping pulse trains from different UWB devices may add up in the victim receiver to a continuous interference pattern. This pattern can destroy a large part of the signal in time, rather than a small fraction.
- 3) Operational restrictions may be difficult to police and enforce. Restrictions on emissions will be much more effective.

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<sup>8</sup> For instance Mini-Circuits parts in the SPL series

### *§37 Use of scramblers*

Scrambling the data will affect the spectrum to some extent but it will be application dependent. Mandating scrambling will not be effective in the protection of existing services. Appropriate operational limits and reliable methods of measurement would provide the necessary framework to ensure UWB devices do not cause harmful interference.

### *§39 Average and Peak Emission levels*

We concur with the Commission's proposal to set limits – for average and peak power – at lower frequencies that are 12 dB below the values that apply above 2 GHz. With the emergence of 3<sup>rd</sup> generation mobile systems, moving the transition point to 2.7 or 3 GHz may warrant consideration by the Commission.

### *§46/47 Cumulative Impact*

As noted in paragraph 34 of the Notice, the cumulative interference caused by multiple UWB devices needs careful attention due to the nature of the UWB emissions. For similar pulse rates and data rates, the RF power peaks will cluster or coincide in time as well as frequency. Although the effect is difficult to quantify, its very existence encourages caution in setting limits for UWB transmissions.

### *§48/49 Measurement Procedures*

Pulse desensitization correction does not fully address the specific nature of UWB emissions. Therefore, Lucent has recommended a technique of measurement that is able to show directly the signal being measured and avoids the need to require complicated analysis and/or calculations.

### *§50 Average and quasi-peak measurements*

As discussed above, Lucent has proposed a correction to the measurement of average limits for UWB burst operations.

### *§51-53 Peak measurements*

Lucent shares the Commission's concern for an adequate method of measurement that is simple, effective and repeatable. We also share the Commission's view that a down-converted wideband signal is such a desirable method. A down-converted wideband signal does not require expensive equipment, is easily calibrated with a reference power source, and nicely visualizes the spectrum being measured. Lucent's proposed measurement setup down-converts the wideband signal to a baseband signal and applies a filter to limit the bandwidth to the specified measurement bandwidth. By tuning the local oscillator used to down-convert the wideband signal to baseband, manufacturers can measure the power in a "window" of spectrum defined by the filter specifications.

### *§54 Antenna measurements*

Lucent believes, where possible, antenna measurements should be avoided – conducted measurements are more accurate and repeatable. Where possible, devices to be measured should be equipped with a connector allowing direct access to the transmitter output. Where required, radiated measurements should use substitution measurements. These are well known and established practices in many test laboratories.

### *§55 Frequency range of measurement*

Lucent notes that, when observed over short intervals, the spectrum of a pulse UWB device is likely to be a more or less clean comb starting at zero Hz and spaced at the pulse repetition interval. Therefore, measurement of UWB spectrum should start at the lower MHz ranges and extend upwards. The smooth, noise-like character of the emitted

spectrum becomes visible only at time scales that are long, compared to detection or processing intervals of a victim receiver.

Respectfully submitted,

Lucent Technologies Inc.

By\_\_\_\_\_

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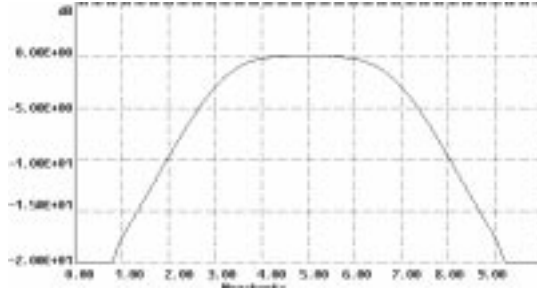
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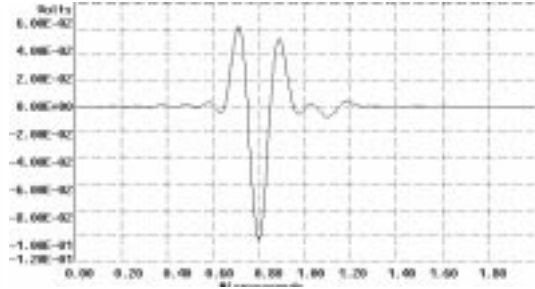
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September 12, 2000

## Annex 1– Example of UWB Pulse Magnitude

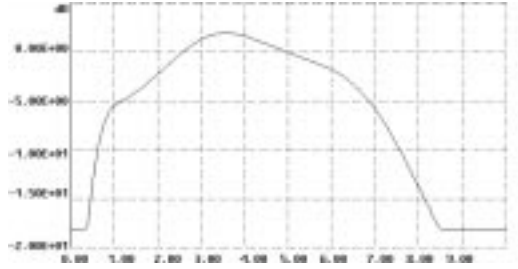


**A. PSD (dB) vs. Frequency (GHz)**

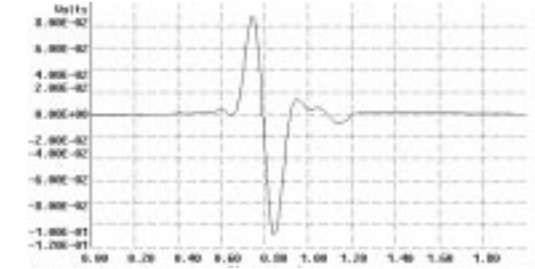


**B. UWB Pulse Magnitude (V) vs. Time (ns)**

$|Peak| = 104.0 \text{ mV}$ , RMS over 1.4 ns = 24.3 mV



**C. PSD (dB) vs. Frequency (GHz)**



**D. UWB Pulse Magnitude vs. Time (ns)**

$|Peak| = 109.0 \text{ mV}$

**Figure A1-1: Illustration of 4 GHz Bandwidth UWB Pulse.**

The figures show the Discrete Fourier Transform (DFT) and the Inverse DFT (IDFT) of a typical UWB emission. The Fourier transform,  $H(f)$  is the product of the IDFT sample time and the DFT. The sample time is 10 picoseconds, thus  $H(5 \text{ GHz}) = 10^{-11}$  Volts/Hz in figures A1-1 A and C. The energy spectral density  $\phi(f) = 2 |H(f)|^2$ . Thus  $\phi(5 \text{ GHz}) = 2 \times 10^{-22}$  Joules/Hz. The peak time responses indicate the peak instantaneous power. This may be as high as 2 times the peak envelope power. The peak power is more appropriate for the high fractional bandwidth.

The limit value of  $\phi(f_0)$  can be computed from the equation  $P_{k50}^2 \approx 6.12 \times 10^{14} P_{dsf}^2 \phi(f_0)$ , since the proposed limit on  $P_{k50}$  is  $10^{-51.2/10} = 7.59 \times 10^{-6}$  Watts (-21.2 dBm). Thus

$$\phi(f_0)_{\text{limit}} \approx \frac{7.59 \times 10^{-6}}{6.12 \times 10^{14} (1.6)^2} = 4.84 \times 10^{-21} \text{ Joules/MHz}$$

The limit is thus 24.2 times the value in the figures. The peak power in figure A1-B is  $0.104^2 = 1.08 \times 10^{-2}$  Watts. The permissible peak power is thus

$$V_{pk}^2 \leq 24.2 \times 1.08 \times 10^{-2} = 0.261 \text{ Watts } (-5.8 \text{ dBW or } 24.2 \text{ dBm})$$

This is higher than the absolute limit proposed in paragraph 43 of the Notice. Paragraph 43 would limit the peak to 0.100 Watts.

Figures A1-1 C and D show the effect of the path loss dependence on frequency. The DFT was multiplied by a low pass function creating a 20 dB per decade frequency dependence as shown in figure C. The IDFT of the figure C function is shown in figure D and has a peak power of  $0.109^2 = 1.19 \times 10^{-2}$  watts. This is 0.4 dB higher than the figure B value. Thus, the path loss frequency dependence has little influence on the peak received power in this case. This applies equally to the intended UWB receiver as to victim devices.

## Annex 2: UWB Interaction With Other Devices Complying With Current Commission Rules

### A2.1 UWB Interference Levels

With the current specification of paragraph 43 of the notice, UWB devices would need to be in relatively close proximity to any wide bandwidth systems to cause significant interference. This can be established by computing the distance at which a single device produces an interference power level equal to the gaussian noise level at the receiver.

The interference level created by a UWB device depends upon the following:

- The repetition rate of the UWB device
- Whether the spectrum is smooth or consists of discrete lines
- Whether there is burst operation so that short-term averages are higher than the 1 MHz specified average.

If the peak power level of an impulse of 3 dB bandwidth B is  $i_b^2$

The energy in the pulse is approximately  $i_b^2/1.5 B$ . Four examples were computed and the range of the bandwidth multiplying factor is shown in the table below.

Filter type	Energy equation
2 pole pair Butterworth	$i_b^2/1.85B$
4 pole pair with 0.7 dB overshoot	$i_b^2/1.40B$
3 pole pair Butterworth	$i_b^2/1.54B$
4 pole pair Butterworth	$i_b^2/1.65B$ .

The first three rows were computed from the impulse responses of Annex 1.

If the UWB device operates at its highest repetition rate for periods exceeding 100 ms, then the average specification of paragraph 43 controls the level, providing the repetition rate exceeds the critical values of Annex 4 ( $R_{p1cr}$  or  $R_{p2cr}$  for discrete and continuous spectrums respectively)<sup>9</sup>. However, if the UWB device operates in bursts with a maximum length less than about 5 ms and a low enough duty cycle (henceforth this will be called burst operation), the peak specification at 50 MHz 10 dB bandwidth will be the only control of the interference level. In this case, the following equations determine the allowable average interference power level.

Let the peak power in a 35 MHz 3 dB bandwidth (50 MHz at -10 dB points) be  $i_p^2$  as before and the repetition rate be  $R_p$ .  $20\text{Log}i_p = -21.2$  dBm per Notice paragraph 43. In the following, the repetition rate is in Mpps and bandwidths are in MHz. Let  $p_B$  = the power in bandwidth B then

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<sup>9</sup> Annex 4 gives values of  $R_{p1cr}$  and  $R_{p2cr}$  of approximately 4 and approximately 16 respectively.

$$p_B \approx i_p^2 \left( \frac{B}{35} \right)^2 \frac{R_p}{1.5B} \quad R_p < B \text{ for the discrete spectrum case}$$

$R_p$  = any value for the continuous spectrum case

With  $P_B$  the power  $p_B$  on a dB scale

$$P_B \approx -21.2 - 20\text{Log}35 - 10\text{Log}1.5 + 10\text{Log}B + 10\text{Log}R_p$$

$$P_B \approx -53.9 + 10\text{Log}B + 10\text{Log}R_p \quad R_p < B \text{ Mpps if discrete spectrum} \quad \mathbf{A2-1}$$

$R_p$  = any value for the continuous spectrum case

If the spectrum consists of equal level discrete lines with separation  $R_p$ , and if  $R_p$  exceeds the bandwidth  $B$  then the complete power of a single spectral line occupies bandwidth  $B$ . Thus, the power in bandwidth  $B$  is the power per spectral line. In this case

$$p_B = \text{Total power/number of lines} = R_p \times \text{Total power}/35$$

$$p_B \approx \left( \frac{R_p}{35} \right) \frac{i_p^2 R_p}{1.5(35)} = \left( \frac{R_p}{35} \right)^2 \frac{i_p^2}{1.5} \quad B \text{ Mpps} < R_p < 35 \text{ Mpps}$$

If  $R_p$  exceeds about 35 Mpps, the peak level specification limits the power level.

This can be reduced to

$$P_B \approx -53.9 + 20\text{Log}R_p \text{ for } \underline{\text{discrete spectrum}} \text{ and } B \text{ Mpps} < R_p < 35 \text{ Mpps} \quad \mathbf{A2-2}$$

If the UWB device operates with a continuous spectrum at a repetition rate below about 16 Mpps, then the 1 MHz average determines the maximum interference level. In this case the interference level is

$$P_B \approx -41.2 + 10\text{Log}B \text{ For continuous spectrum and } R_p < \approx 16 \text{ Mpps} \quad \mathbf{A2-3}$$

Table A2-1 below gives the maximum average interference power at 3 typical bandwidths with the interference level limited by the current paragraph 43 specification.

Note: Equation A2-3 is exact, so it is used in all cases in which it is applicable.

There is a special case for bandwidths below 1 MHz. If the bandwidth is less than 1 MHz and the UWB devices do not operate in a burst mode then the average specification at 1 MHz controls the interference level. This level limit is  $-41.2$  dBm if the spectrum is discrete. Otherwise, the above equations apply for the lower bandwidth.

## A2.2 Interference Distances

High bandwidth systems, such as those based on IEEE 802.11 specifications, served as typical systems in our analysis to demonstrate the effects that UWB devices would have on all such broadband systems.

The IEEE 802.11 CCK and OFDM systems are about 3 dB less sensitive to a tone signal than to a gaussian noise level of the same average power. In the cases in which the UWB interference consists of multiple impulses during a CCK or an OFDM symbol, the sensitivity to the interference is about the same as to a gaussian noise signal of the same level. Single carrier systems without direct sequence spreading

(including the frequency hopping systems) are about 6 dB less sensitive to a tone signal.

The Bluetooth modulation scheme is similar in nature to that of 802.11 FH @ 1 Mbit/s. However, the Bluetooth receiver sensitivity is only –70 dBm as given in the Bluetooth Specification. Therefore, a Bluetooth receiver cannot be simply characterized by a noise factor of 7 dB, it is designed for shorter range and very low cost.

The following parameters apply to 802.11 CCK:

- Path loss to 1 meter = 41 dB
- Noise level at 7 dB noise figure = -97 dBm
- Equivalent gaussian noise level of a tone  $\approx$  Tone power level – 3 dB
- The allowable path loss beyond 1 meter is then 97-41+ equivalent level = 56 dB + equivalent level.

*The following apply to 802.11 FH:*

- Path loss to 1 meter = 41 dB
- Noise level at 7 dB noise figure = -105 dBm
- Equivalent gaussian noise level of a tone  $\approx$  Tone power level – 6 dB
- The allowable path loss beyond 1 meter is then 105-41 + equivalent level = 64 dB + equivalent level.

The following parameters apply to 802.11 OFDM:

- Path loss to 1 meter = 47 dB
- Noise level at 7 dB noise figure = -95 dBm
- Equivalent gaussian noise level of a tone  $\approx$  Tone power level – 3 dB
- The allowable path loss beyond 1 meter is then 95-47+ equivalent level = 48 dB + equivalent level.

With the allowable path loss = A, the equation for distance (D) is

$$D = 10^{\frac{A}{20}} \text{ meters for } A \leq 20 \text{ dB and}$$

$$D = 10 \times 10^{\frac{A-20}{35}} \text{ for } A > 20 \text{ dB.}$$

The number 35 is  $10\alpha$ , in which  $\alpha = 3.5$  is the attenuation exponent.

Bandwidth (MHz)	System	UWB Spectrum type D (discrete) C(continuous)	Operation B (Burst) NB (Non burst)	Applicable equation / Repetition rate (Mpps)	Maximum average interference power (dBm)	Interfering signal type T (tone) R (resolvable impulses) G (Gaussian)
0.700	802.11 FH	D	B	Eq. 2/35	-23.0	T
		D	NB	B<1MHz	-41.2	T
		C	B	Eq. 2/35	-23.0	G see note 1
		C	NB	Eq. 3	-42.7	G
11	802.11 CCK	D	B	Eq. 2/35	-26.0	T
		D	NB	Eq. 1/4	-37.5	R
		C	B	Eq. 2/35	-26.0	G see note 1
		C	NB	Eq. 3	-30.8	G
16.5	802.11 OFDM	D	B	Eq. 2/35	-23.0	T
		D	NB	Eq. 1/4	-35.7	R
		C	B	Eq. 2/35	-23.0	G see note 1
		C	NB	Eq. 3	-29.0	G

Table A2-1: UWB Average Power Interference Levels.

**Note 1: Burst operation with a continuous spectrum generates a signal with the peak level shown. However, the average signal level is less than this and the signal is approximately gaussian. If any short bursts occur with a repetition rate exceeding about 35 Mpps, the peak measurement will register a higher level than the individual impulse peak, thus the individual impulse peaks will be less than the maximum allowed for single impulses.**

Tables A2-2a,b,c give the distances from the UWB device to the victim receiver at which the UWB interference is approximately equal to the background gaussian noise. The power levels are taken from table A2-1.

UWB operating condition	Average power Level	Equivalent gaussian power level	Path loss beyond that at 1 meter	Interference distance
Burst operation, discrete or continuous spectrum	-23 dBm tone	-26 dBm	30 dB	19.3 m
Non burst operation, discrete spectrum	-37.5 dBm	-37.5 dBm	18.5 dB	8.4 m
Non burst operation, continuous spectrum	-30.8 dBm	-30.8 dBm	25.2 dB	14.1 m

**Table A2-2a: Maximum interference distances for IEEE 802.11 CCK systems.**

UWB operating condition	Average power Level	Equivalent gaussian power level	Path loss beyond that at 1 meter	Interference distance
Burst operation, discrete spectrum	-23 dBm tone	-29 dBm	35 dB	26.8 m
Burst operation, continuous spectrum	-23 dBm see note 1	<-29 dBm	<35 dB	<26.8 m
Non burst operation, discrete spectrum	-41.2 dBm tone	-47.2 dBm	16.8 dB	6.9 m
Non burst operation, continuous spectrum	-41.2 dBm	-41.2 dBm	22.8 dB	12 m

**Table A2-2b: Maximum interference distances for IEEE 802.11 FH systems.**

UWB operating condition	Average power Level	Equivalent gaussian power level	Path loss beyond that at 1 meter	Inter-ference distance
Burst operation, discrete or continuous spectrum	-23 dBm tone	-26 dBm	22 dB	11.4 m
Non burst operation, discrete spectrum	-35.7 dBm	-35.7 dBm	12.3 dB	4.1 m
Non burst operation, continuous spectrum	-29 dBm	-29 dBm	19 dB	8.9 m

Table A2-2c: Maximum interference distances for IEEE 802.11 OFDM systems.

The -23 dBm level for frequency hopping systems and discrete UWB spectrum occurs with a repetition rate of 35 Mpps. Thus, there will be at most 3 spectral lines in a frequency hopping band of 82 MHz. With non-burst UWB operation and discrete spectrum, the spectral lines will be approximately spaced every 4 MHz when the level is maximum. With non-burst operation and continuous spectrum, all frequencies may be affected. For this reason, the last row of the table may be most significant for the frequency hopping systems.

UWB devices used for the radar-like application will probably operate simply and generate discrete spectrums. However, a communication transmitter must generate some power in a non-discrete spectrum since a transmitted line spectrum contains no information. Nevertheless, it can be expected that many UWB systems will operate with discrete spectrums. Thus, if the average specification can be improved the interference distance can be reduced for most interfering devices without compromising the communications application. Compare rows 1 and 2 of table A2-2a, rows 1 and 3 of table A2-2b and row 1 and 2 of table A2-2c.

## **Annex 3: Peak envelope power of the impulse response of a bandpass filter**

### **A3.1 Introduction**

This annex is a study of the “pulse desensitization correction factor” of paragraph 48 of the Notice and its utilization in understanding the paragraph 43 specification.

The means of measuring the “peak signal strength” at 50 MHz bandwidth (paragraph 43) is not established in the Notice. The peak signal strength depends on more than just the bandwidth of the measurement device. The pulse desensitization factor was mentioned in the Notice and the HP equipment value of this factor is a good guess as a means of interpreting the specification. This factor is shown to depend significantly on more than just the bandwidth of the filter used to measure the peak signal strength.

An interpretation of the peak power versus energy density is given using this factor. Its relationship to a baseband filter response is given.

### **A3.2 Discussion**

The Notice specifies the limit on the peak of an Ultra WideBand (UWB) pulse in terms of the peak response of a 50 MHz filter. If the UWB spectrum is flat over 50 MHz then the peak envelope power is proportional to the square of the bandwidth. The peak envelope power of the impulse response of a 1 MHz filter is developed here. This can be easily extended to the 50 MHz response.

The “pulse desensitization correction factor” of the Notice is proportional to the peak envelope power of the impulse response of a bandpass measurement filter. This factor is a function of the actual measurement filter. It is not specified how the 50 MHz peak will be measured. It is likely that the “pulse desensitization factor” will enter into the determination in some way.

$P_{k1}$  = the peak RMS envelope voltage through a symmetrical 1 MHz resolution bandwidth filter

$P_{b.5}$  = the baseband peak response of a 500 kHz low pass filter of unity gain which is the baseband equivalent of the 1 MHz resolution bandwidth filter.

$\tau$  = the input rectangular pulse time duration (of the approximate impulse)

$v_{r1}$  = the input rectangular pulse voltage

$E_p$  = the total energy per input pulse

$\Phi(f_0)$  = the input energy spectral density at frequency  $f_0$ .

$B_n$  = the equivalent noise bandwidth of the input pulse ( $B_n = 1/2\tau$ ).

Let the impulse response of a 500 kHz low pass filter be  $v(t)$ . This is the response when  $\tau \ll 1/500$  kHz and  $\tau v_{r1}$  equals one. It is proportional to the impulse weight  $\tau v_{r1}$ .

Consider the bandpass equivalent filter of 1 MHz bandwidth centered at  $f_0$  and the response to a signal of energy spectral density  $\Phi(f_0)$  that is flat over the passband of the filter. The envelope response of this filter has the same shape as the equivalent

baseband filter response and has twice the energy if the energy spectral density is the same. This assumes that  $v(t)$  is the response of a baseband filter with gain = 1 defined at  $f \geq 0$  only. The envelope response of the bandpass equivalent is  $2v(t)\cos 2\pi f_0 t$  if the bandpass filter also is considered to have a gain of 1. The envelope power is 1/2 of the voltage squared, that is, the RMS envelope is  $\sqrt{2}v(t)$ .

Thus, the RMS peak envelope power of the impulse response of the 1 MHz bandwidth resolution bandwidth filter is

$P_{k1} = \sqrt{2}P_{b.5}$  in which  $P_{b.5}$  is the peak voltage of the unit impulse response of the 500 kHz low pass filter.

$P_{k1}$  divided by the 3 dB bandwidth of the measurement filter is the quantity referred to as the “pulse desensitization factor” in the Notice. If this is  $P_{dsf}$  then

$P_{dsf} = \sqrt{2}P_{b.5}$  for a 1 MHz resolution bandwidth filter.

Consider a normalized 1 ohm load so that power = voltage squared. Then let  $\tau v_{r1}$  be the input to the 500 kHz filter. The equivalent rectangular bandwidth of the impulse is  $1/2\tau$  thus

$$\begin{aligned} E_p &= \tau v_{r1}^2 \\ \phi(0) &= E_p / B_n = 2 \tau^2 v_{r1}^2 \text{ or} \\ \tau v_{r1} &= \sqrt{\phi(0)/2} \end{aligned}$$

The impulse response voltage peak is proportional to  $\tau v_{r1}$ , thus

$$P_{k1}^2 = C_v (v_{r1} \tau)^2 = C_v \frac{\phi(0)}{2} = 2P_{b.5}^2, \text{ from which}$$

$$C_v = \frac{2P_{b.5}^2}{(v_{r1} \tau)^2} = \frac{2P_{b.5}^2}{10^{-12}} \text{ and}$$

$$P_{k1}^2 = 10^{12} P_{b.5}^2 \phi(0)$$

Thus, from the above low pass impulse response and assuming the same energy spectral density at frequency  $f_0$ , the peak RMS envelope power measured through a 1 MHz 3 dB resolution bandwidth filter is

$$P_{k1}^2 = 10^{12} P_{dsf}^2 \frac{\phi(f_0)}{2}, \quad 1-1$$

providing the energy spectral density is flat over the 1 MHz bandwidth<sup>10</sup>. The peak envelope power is proportional to the bandwidth thus

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<sup>10</sup> This is also covered in Attachment 1 to the WINForum comments. Refer to page 14, equation 29.

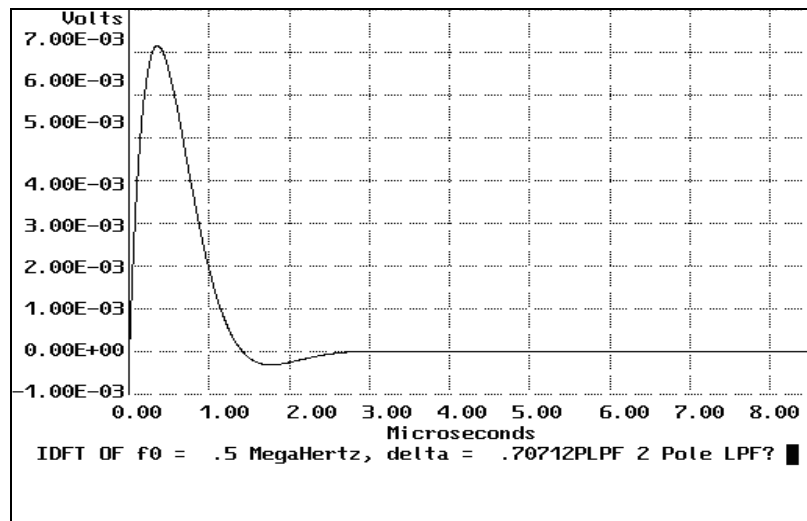
$$P_{y \max peak}(t) = 2|G(f)|_{\max}^2 B_{imp}^2$$

$$\text{Peak envelope power} = P_k^2 = \text{Bandwidth}^2 \times P_{k1}^2$$

with Bandwidth expressed in MHz and  $\phi(f_0)$  in Joules/Hz.

Section A3.3 shows computations of  $P_{\text{dsf}}$  for some common low pass filters. The values in section A3.3 range from 1.78 to 2.02. Attachment 1 to the WINForum comments shows computations of values that range from 1.61 to 1.79. The HP reference of the Notice mentions a value of 1.6 corresponding to an HP spectrum analyzer. From the section A3.3 and WINForum computations, it can be seen that the value is lower for flat bandpass filters with steep skirts.

### A3.3 Example Pulse Desensitization Factor Calculations



**Figure A3-1: Impulse Response of a Two Pole Butterworth Low Pass Filter and Relationship to the Pulse Desensitization Factor.**

Above figure shows the impulse response of a 500 KHz, 2 pole Butterworth low pass filter. the baseband signal is  $v(t)$ .  $2v(t)\cos(2\pi f_0 t)$  is the impulse response of a 1 MHz Bw symmetrical bandpass filter centered at  $f_0$  in which each sideband shape is a 2 pole Butterworth bandpass skirt and the input energy spectral density is the same as that of the low pass filter.  $|v(t)|$  is the envelope. The envelope RMS voltage out of the 1 MHz bandwidth bandpass filter at frequency  $f_0$  is 3 dB less than  $\sqrt{2}v(t)$ .

	V(t)	RMS envelope
Mean over 2.8 $\mu$ s	1.943 mV	2.75 mV
RMS over 2.8 $\mu$ s	3.148 mV	4.45 mV
Peak	7.155 mV	10.12 mV

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$p_{y\text{maxpeak}}(t)$  is the peak power of the impulse,  $2|G(f)|^2$  is the maximum value of the energy spectral density  $[\phi(f)_{\text{max}}]$  and  $B_{\text{imp}} = P_{\text{dsf}}B_{3\text{dB}}$ .

This response as give in figure A4-1) is the IDFT consisting or  $2^{11}$  point with 5 ns between time domain values. The effective impulse is thus 1 Volt times 5 ns =  $5 \times 10^{-9}$  Volt-s or  $5 \times 10^{-3}$  Volt- $\mu$ s.

Peak output =  $7.155 \times 10^{-3} \text{ V} / 5 \times 10^{-3} \text{ Volt-}\mu\text{s} = 1.431 \text{ Volt per Volt-}\mu\text{s}$ .

Peak RMS envelope at  $f_0 = P_{\text{dsf}} = 1.431\sqrt{2} = \mathbf{2.02}$  Volt RMS per Volt- $\mu$ s.

Peak envelope/RMS envelope ratio over 2.8  $\mu$ s = 2.27 corresponding to 7.1 dB.

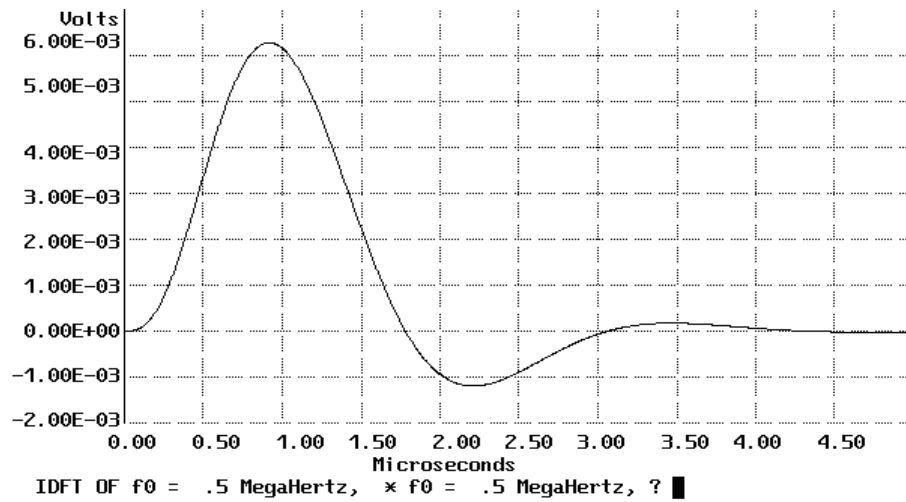


Figure A3-2: Impulse Response of 4 pole filter with + 0.7 dB overshoot and 500 kHz 3 dB bandwidth.

Input = 1 Volt x 5 ns or  $5 \times 10^{-3}$  Volt- $\mu$ s.

Peak =  $6.28 \times 10^{-3}$  Volt/ $5 \times 10^{-3}$  Volt- $\mu$ s = 1.256 V/V- $\mu$ s peak.

RMS over 4.5  $\mu$ s =  $2.502 \times 10^{-3}$  Volt

Envelope RMS =  $1.41 \times 1.26 = 1.78$  (pulse desensitization factor)

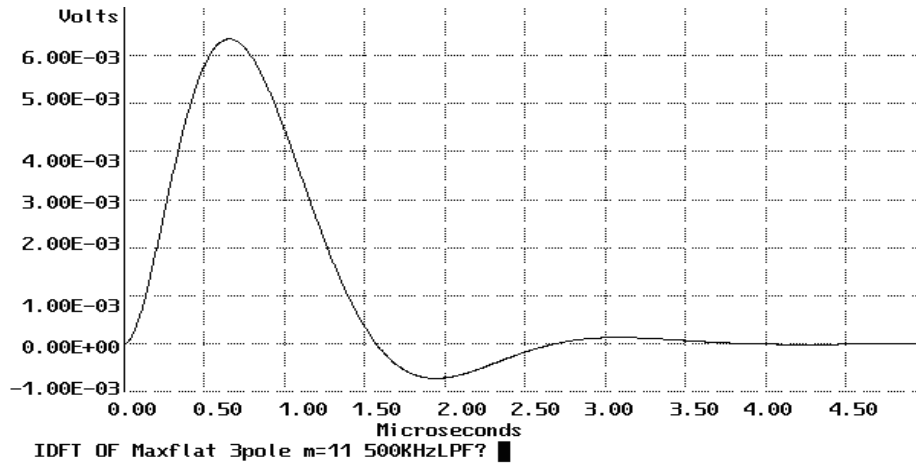


Figure A3-3: Impulse Response of 3 pole Butterworth filter with 500 kHz 3 dB bandwidth.

Input = 1 Volt x 5 ns or  $5 \times 10^{-3}$  Volt- $\mu$ s.

Peak =  $6.347 \times 10^{-3}$  Volt/ $5 \times 10^{-3}$  Volt- $\mu$ s = 1.27 V/V- $\mu$ s peak.

RMS over 4.0  $\mu$ s =  $2.557 \times 10^{-3}$  Volt

$$\text{Envelope RMS} = 1.41 \times 1.27 = \mathbf{1.80} \text{ (pulse desensitization factor)}$$

### **A3.4 Conclusion**

This annex has addressed the Pulse Desensitization Correction Factor (PDCF) of paragraph 48 of the Notice. The value of this factor was calculated for some typical filter types and the response shape was shown. The WiNforum comments on the UWB Notice of Inquiry was also reviewed. The factor varies from 1.61 to 2.02 for the filter shapes analyzed.

It is concluded that a more complete filter specification is necessary to fully define the peak UWB signal.

## Annex 4: The specification recommended in the Notice

### A4.1 Introduction

The probable energy density requirement controlling the 50 MHz bandwidth peak power is given. It is based on using a published HP pulse desensitization factor.

The peak versus average power is used to compute critical repetition rates. At rates below these, the peak specification governs, above them, the average.

For fixed rep rates, the critical value is about **4 Mpps** (Million pulses per second).

For random repetition intervals the critical average repetition rate is about **16 Mpps**.

The dependence of the critical rates on the specification parameters are also investigated.

Notes on other potential study items are included briefly at the end of section 2.

### A4.2 Discussion

Paragraph 43 of the UWB Notice recommends that the peak pulse power be measured through a filter with a 10 dB bandwidth of 50 MHz. The 3 dB bandwidth of a 6 pole-pair maximally flat filter is about 0.7 times the 10 dB bandwidth. Thus, the 3 dB bandwidth of the measurement filter will be taken as 35 MHz. Peak pulse power for a wideband pulse (bandwidth  $\gg$  measurement bandwidth) is proportional to the measurement bandwidth squared. Thus, with  $P_{k50}$  = the peak RMS envelope voltage and  $P_{k50}^2$  the peak pulse power

$$P_{k50}^2 \approx 10^{12} (35 P_{dsf})^2 \frac{\phi(f_0)}{2} = 6.12 \times 10^{14} P_{dsf}^2 \phi(f_0) \quad A4-1$$

with  $\phi(f_0)$  in Joules/Hz

This assumes that the UWB bandwidth greatly exceeds 50 MHz so that  $\phi(f)$  is flat over the 50 MHz range.

The limit value of  $\phi(f_0)$  can be computed from this equation, since the proposed limit on  $P_{k50}^2$  is  $10^{-51.2/10} = 7.59 \times 10^{-6}$  Watts (-21.2 dBm). Thus

$$\phi(f_0)_{limit} \approx \frac{7.59 \times 10^{-6}}{6.12 \times 10^{14} (1.6)^2} = 4.84 \times 10^{-21} \text{ Joules/Hz} \quad A4-2$$

Paragraph 43 recommends that the average specification be the same as now in Part 15, that is -41.2 dBm EIRP measured as a voltage average over the maximum 100-millisecond interval. It is desired to determine the range over which the peak specification governs. Three conditions will be evaluated.

1. The repetition rate greater than 1 Mpps or the modulation is sample PPM so that the power per spectral line is the average in a 1 MHz bandwidth measurement filter.
2. The repetition rate is lower than 1 Mpps, so that the average power in a 1 MHz filter is proportional to the bandwidth times the repetition rate.

3. The pulse sequence is purely random with an average rate greater than 1 Mpps.

**A4.2.1 Case 1: Constant repetition rate greater than 1 Mpps or PPM with an average rate greater than 1 Mpps.**

In this case, the average power is the power per spectral line.

The case of PPM with an average repetition rate of 20 Mpps was investigated in the WINForum comments<sup>11</sup>.

With  $B_n = 1$  MHz and no modulation, the power per spectral line is  $p_y = 20^2 \phi(f_0)$ . This is the same maximum value of the 1 MHz filter response for the PPM case with the three values of pulse position variation of the figures. Thus the case analyzed by WINForum ( $R_p = 20$  Mpps) has the same average power in the highest power spectrum peaks as does the constant repetition rate case.

The following is correct for a constant repetition rate.

Let  $R_p$  = the repetition rate in Mpps (millions of pulses per second).

The power per line is the total power divided by the number of lines

$$\text{Average power} = \text{power per line} = \frac{E_p R_p}{B_n / R_p} = \frac{E_p R_p^2}{B_n}$$

$$\text{Peak pulse power} = P_{k50}^2 \approx 6.12 \times 10^{14} P_{dsf}^2 \phi(f_0) = 6.12 \times 10^{14} P_{dsf}^2 \frac{E_p}{B_n}$$

$$\text{Peak power/Average power} = \frac{612 P_{dsf}^2}{R_p^2} \text{ with } R_p \text{ in Mps.}$$

If this exceeds 100 (20 dB) then the peak value governs, thus the critical value of  $R_p$  (below which the peak governs) is

$$R_{p1cr} \approx 2.5 P_{dsf} \text{ Mpps.}$$

Using the 1.6 value of  $P_{dsf}$  for the HP spectrum analyzer, the value is

$$R_{p1cr} \approx 4.0 \text{ Mpps with the likely pulse desensitization value.}$$

If the repetition rate exceeds this then the average power specification governs the permissible value.

$R_{p1cr}$  is dependent on the specified measurement bandwidths and the specified peak and average power levels. Let

$B_r$  = the 3 dB measurement bandwidth for the peak divided by the 3 dB measurement bandwidth for the average. This is approximately  $35/1 = 35$  in the Notice.

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<sup>11</sup> WINForum comments, Attachment 1, Section 4.5, page 18-19, Figures 3-5.

$P_a$  = the peak power specified divided by the average power specified. This is 100 in the notice.

**$R_{p1cr}$  is proportional to  $\sqrt{B_r/P_a}$ , thus in general terms**

$$R_{p1cr} \approx 4.2 P_{dsf}^2 \sqrt{B_r/P_a} \cdot \quad A4-3.$$

#### **A4.2.2 Case 2: The repetition rate is lower than 1 Mpps**

The average in this case is less than it would be if the repetition rate was greater than 1 Mpps. Thus, in all cases in which the critical value of the repetition rate exceeds 1 Mpps, the peak specification governs. For case 1,  $P_a/B_r$  must exceed approximately 114 for the average to govern at repetition rates below 1 Mpps. This average is less than 3 in the Notice.

#### **A4.2.3 Case 3: The pulse repetition interval has a random duration with an average rate greater than 1 Mpps.**

The WINForum comments<sup>12</sup> show that if the pulse repetition interval has a completely random duration and the average repetition rate is high relative to the measurement bandwidth, then the power spectrum is continuous and flat over the measurement bandwidth. Further, in this case, the time domain signal description approaches gaussian noise<sup>13</sup>.

Obviously the average power in this case is less than the power per line.

$$\text{Average power per 1 MHz} = \frac{E_p R_p}{B_n} \text{ with } B_n \text{ in MHz.}$$

Peak envelope power in 50 MHz band

$$= P_{k50}^2 \approx 6.12 \times 10^{14} P_{dsf}^2 \phi(f_0) = 6.12 \times 10^{14} P_{dsf}^2 \frac{E_p}{B_n}$$

$$\text{Peak/Average} = \frac{612 P_{dsf}^2}{R_p}$$

If the peak/average ratio exceeds 100 then the peak specification governs. If this repetition rate is named  $R_{p2cr}$  then solving the inequality gives

$$R_{p2cr} \approx \frac{612 P_{dsf}^2}{100} = 16 \text{ Mpps with } P_{dsf} = 1.6.$$

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<sup>12</sup> See Attachment 1 to the WINForum comments, Section 4.4, pages 16 and 17.

<sup>13</sup> This is a consequence of the fact that the phase of each pulse is stochastic and evenly distributed over 0 to  $2\pi$  with respect to the pulses (nearby in time) that also contribute to the filter response. Thus, if this randomness can be achieved by any means including slight dithering, the spectrum can be made continuous.

Using the 1.6 value for the HP spectrum analyzer, the value is  $R_{p2cr} \approx 16$  Mpps. If the repetition rate exceeds this then the average power specification governs the permissible value.

***$R_{p2cr}$  is proportional to the ratio  $B_r/P_a$ , thus in general terms***

$$R_{p2cr} \approx 17.5 P_{dsf}^2 \frac{B_r}{P_a} . \quad A4-4$$

Thus, the repetition rate at which the full pulse power is permitted is between about 4 Mpps and 16 Mpps with the specification of the Notice if the transmission is continuous over any 100 ms interval. The higher repetition rate has more communication capacity. Thus, to achieve the highest communication capacity, a modulation scheme that produces an approximately random pulse interval is best.

UWB radar like applications do not need extremely high repetition rates. Thus, if the paragraph 43 specs are accepted, it is not likely that the average specification will ever be utilized for these.

#### ***A4.2.4 Effect of averaging over 100 ms.***

An artifact of the Part 15 average specification is that the measurement is a voltage (field strength) average taken over 100 ms. This is measured as the output of a spectrum analyzer with a 10 Hz video filter and a 1 MHz resolution bandwidth filter. Thus, the average while on can be higher if the equipment operates in bursts shorter than 10 ms (as specified), or about 3 ms (as measured) and operates at a reduced duty cycle.

If the UWB device operates in this bursty mode, the average while on can be significantly higher than the specified average value. With this mode of operation, the average specification is not effective and only the peak specification controls the level. That is, devices can operate at such high burst rates that the proposed 50 MHz filter no longer resolves the pulses and the limit is controlled only by the inter-pulse overlap of the 50 MHz filter.

### **A4.3 Conclusion**

It has been shown that the energy spectral density of the proposed peak level in paragraph 43 of the Notice is about  $4.8 \times 10^{21}$  Joules/Hz with a particular interpretation of the filter 3 dB/10dB bandwidth ratio and the HP defined PDSF.

If the UWB devices do not operate in a burst mode as defined above, the average power specification of paragraph 43 controls the interference level of UWB devices if the repetition rate of the device exceeds a critical value. With discrete line spectra, as is likely with imaging devices, the critical value is about 4 Mpps. With continuous line spectra, as is likely for communication devices, the critical value is about 16 Mpps. It is further shown how these critical values change if the peak and average parameters are changed.

If the devices operate in a burst mode, the average specification, as now applied in Part 15, has no effect on the interference level the UWB devices create relative to digital communication victim systems.